SUMMARY of the sessions

Novel Technical Advancements (Detector / Experiment)

Jets and Novel Probes (Experiment)

Salvatore Fazio
(Brookhaven National Lab)

EIC Users Meeting – Argonne National Lab
07-09 July, 2016

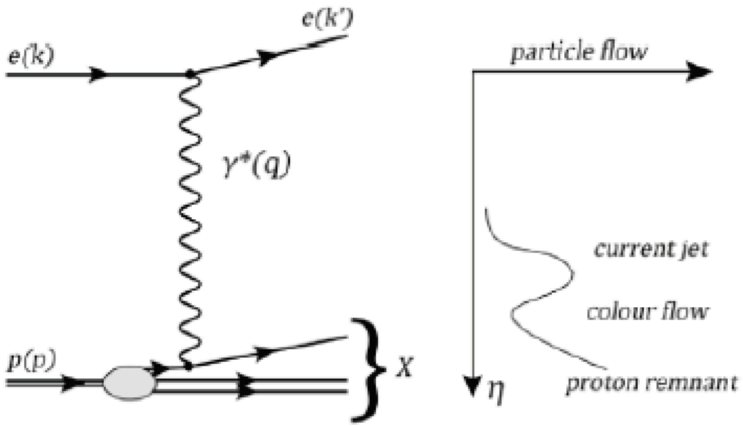
BROOKHAVEN NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Charles Hyde

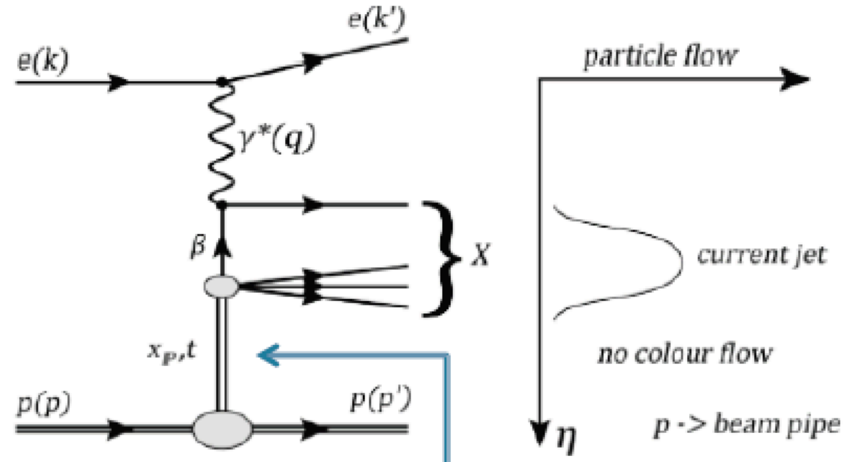
Forward Tagging as a Probe of Hadronic and Nuclear Dynamics

Deep Inelastic Scattering (DIS)



Diffractive Scattering (DDIS)

- ~10% of HERA DIS events



Rapidity Gap: $\Delta\eta \geq 2$

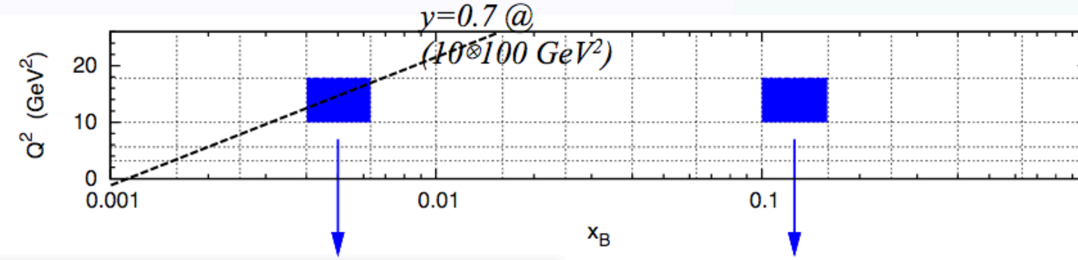
Proton Remnant:

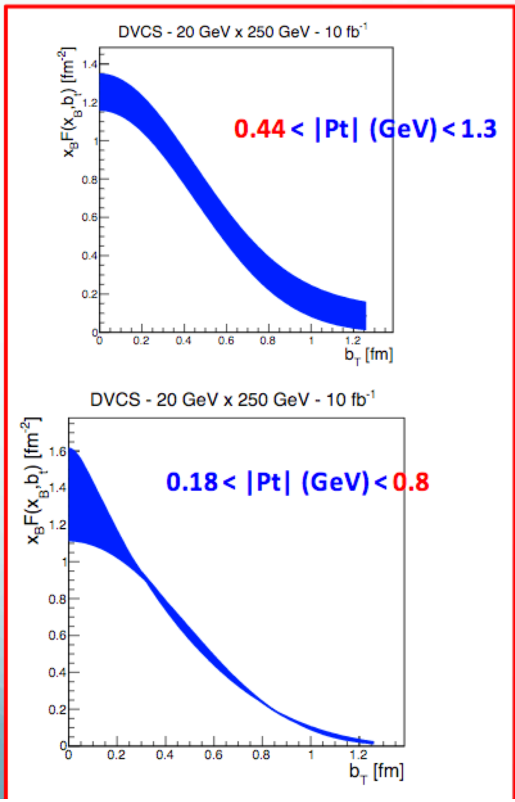
- Di-quark/ tetra-quark color triplet
- Color octet
- The beam remnant fragmentation is as important as the 'current jet'
- Never before studied in detail

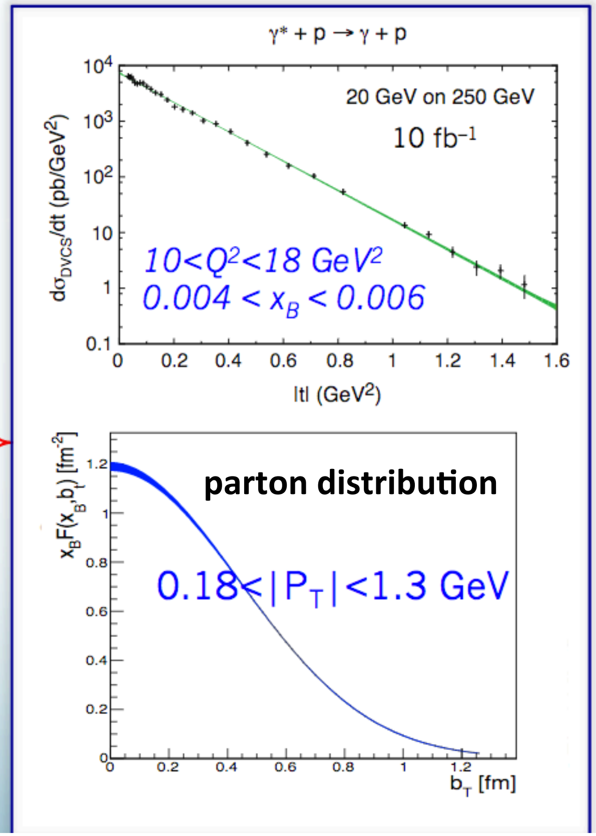
Deep Virtual Exclusive Scattering Transverse Spatial Imaging *vs.* x_{Bj}

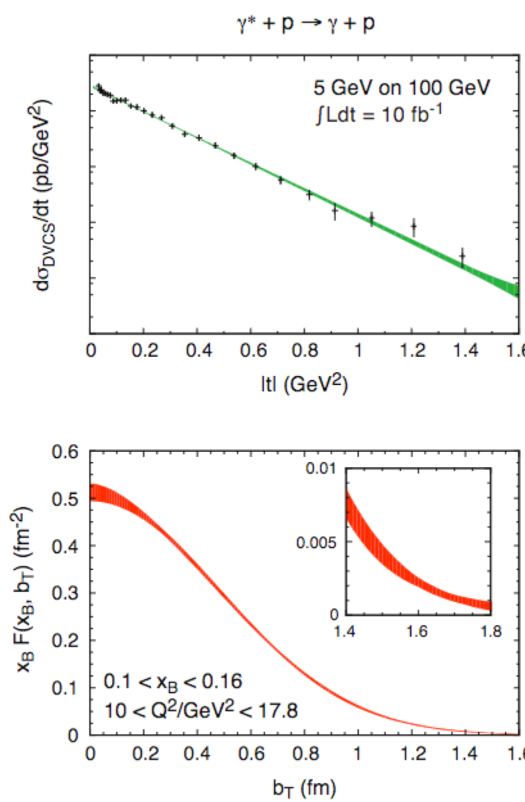
Charles Hyde

- Detector Acceptance
  - eRHIC: new IR design: $0.18 \leq p_T$
  - JLEIC: Far-Forward spectr. $0.0 \leq p_T$ for $x_{Bj} > 0.003$









Charles Hyde

DIS and Many Body Nuclear Dynamics

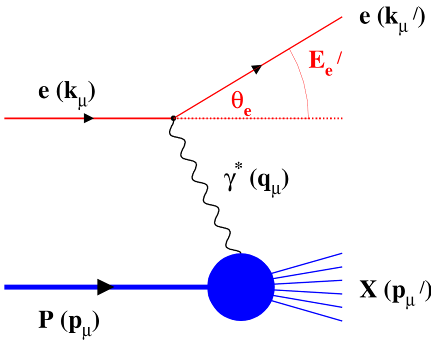
- DIS at different x, Q^2 ranges probes particular configurations in the nucleus
- Forward tagging of spectator/recoil nucleons… to observe the dynamics of the active configurations.
- Illustrative Examples:
  - $x>1$ ~6-quark bags
  - $0.2 < x < 0.7$ Nuclear Binding, Short Range Correlations
  - $x \approx 0.1$ Anti-shadowing: Hard Core on NN Force
  - $x < 0.1$ Coherent Diffraction: Multiple nucleons
  - $x \lll 0.1$, $Q^2 \gg 1\,\mathrm{GeV}^2$ Coherence → Saturation Transition

EIC physics program overview

Alexander Kiselev

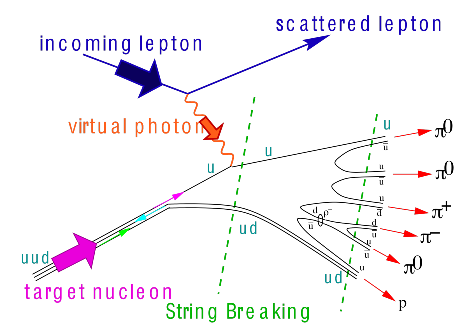
Inclusive Reactions in ep/eA:

- Physics: Structure Functions: g_1, F_2, F_L
- → Very good scattered electron ID
- → High energy and angular resolution of e' (defines kinematics $\{x,Q^2\}$)



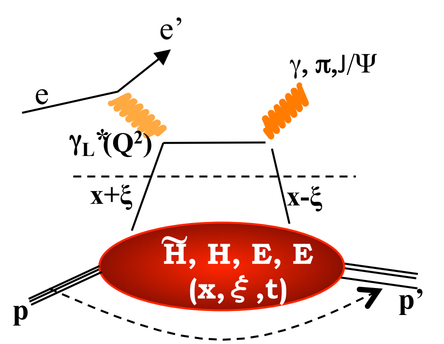
Semi-inclusive Reactions in ep/eA:

- Physics: TMDs, Helicity PDFs, FFs (with flavor separation); di-hadron correlations; Kaon asymmetries, cross sections; etc
- → Excellent hadron ID: $p^{\pm}$,$K^{\pm}$,$p^{\pm}$ separation over a wide $\{p, \eta\}$ range
- → Full Φ-coverage around γ^*, wide p_t coverage (TMDs)
- → Excellent vertex resolution (Charm, Bottom separation)



Exclusive Reactions in ep/eA:

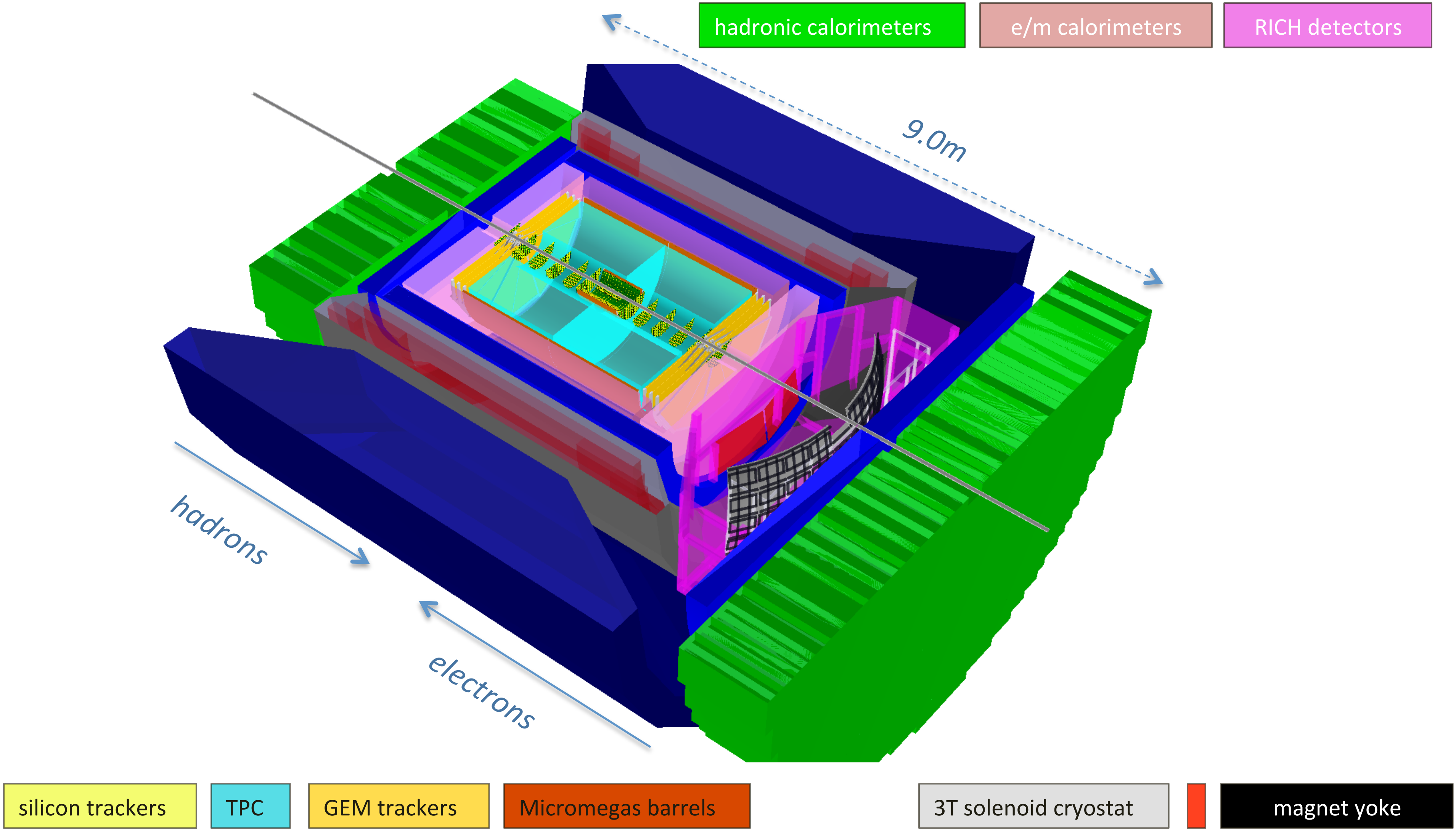
- Physics: DVCS, exclusive VM production (GPDs; parton imaging in b_T)
- → Exclusivity (large rapidity coverage; reconstruction of all particles in a given event)
- → High resolution, wide coverage in t → Roman pots
- → (eA): veto nucleus breakup, determine impact parameter of collision
- → Sufficient acceptance for neutrons in ZDC



BeAST detector layout

Alexander Kiselev

-3.5 < η < 3.5: Tracking & e/m Calorimetry (hermetic coverage)



BeAST Summary slide

Alexander Kiselev

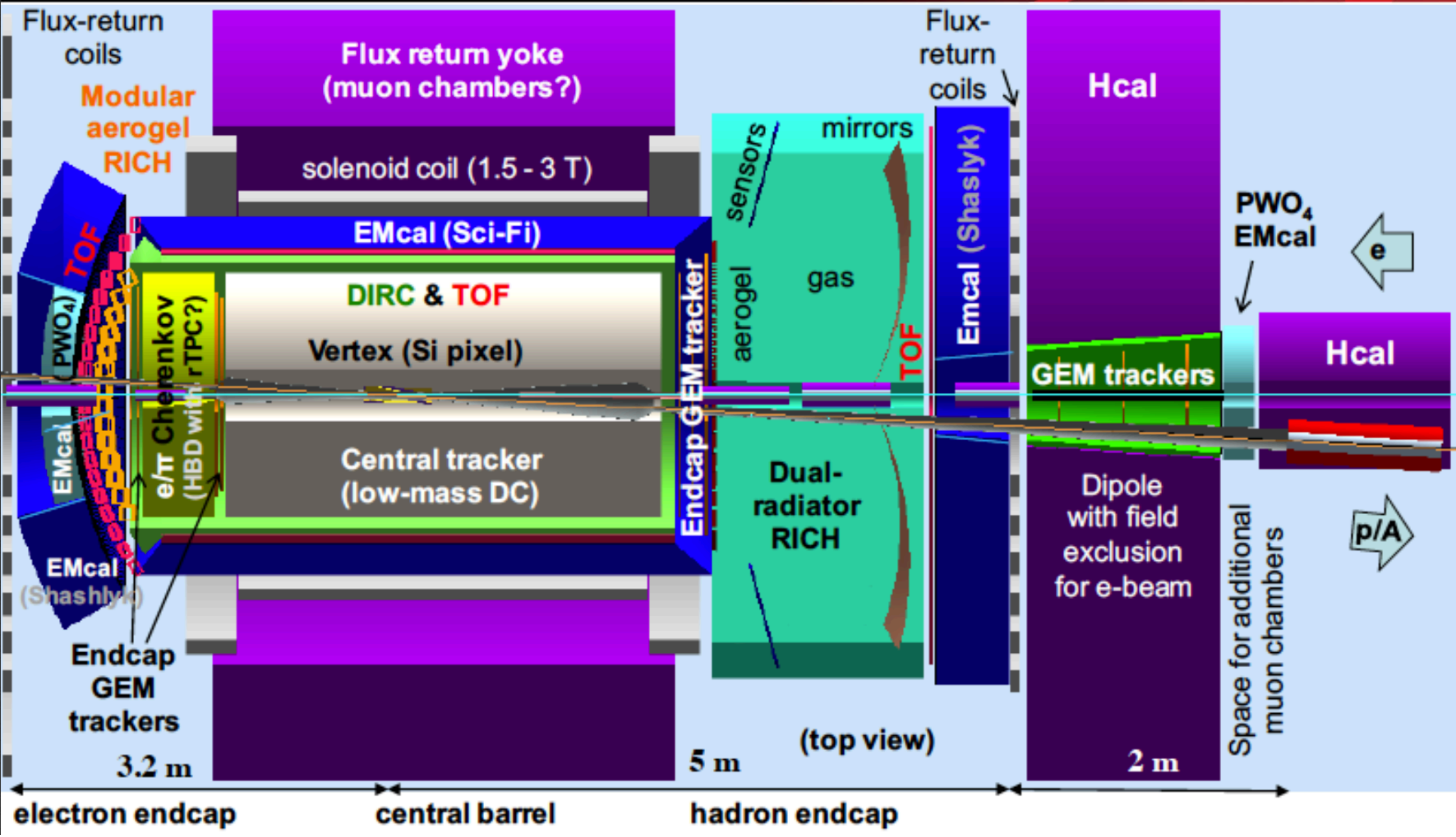
- A flexible eRHIC detector configuration is put together
- It is based on either proven components or the ongoing R&D

- Present and next items on the ToDo list:
  - Decide on the PID detector configuration
  - PID algorithm development: either write parts from scratch or import from elsewhere (and then they better belong to a shared EIC software "pool")
  - Track finder algorithm for central rapidities (preferably within software consortium WPs, so portable between frameworks and generic enough)

  - Further optimization of various detector technologies to meet the detector requirements imposed by physics

Rik Yoshida

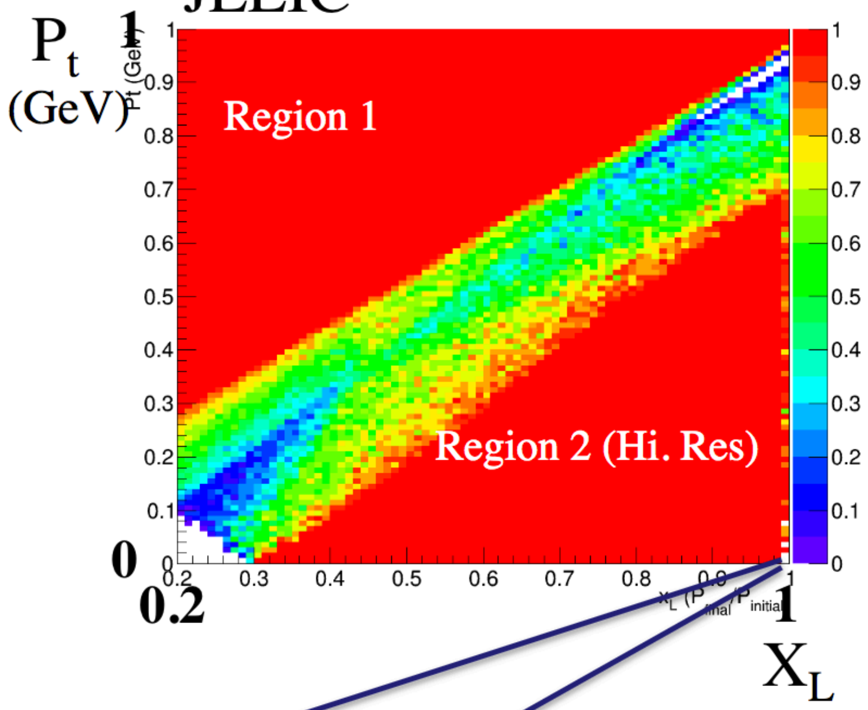
Current JLEIC Concept

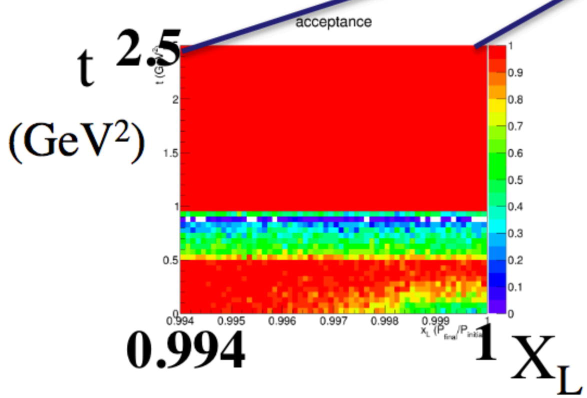


Rik Yoshida

Acceptance for p' in DDIS

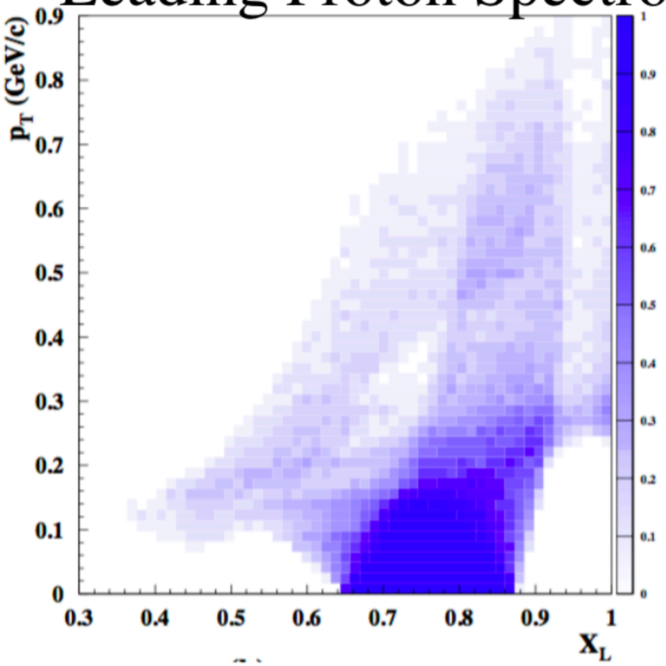
JLEIC





ZEUS

Leading Proton Spectrometer



Acceptance in diffractive peak (X_L>~.98)

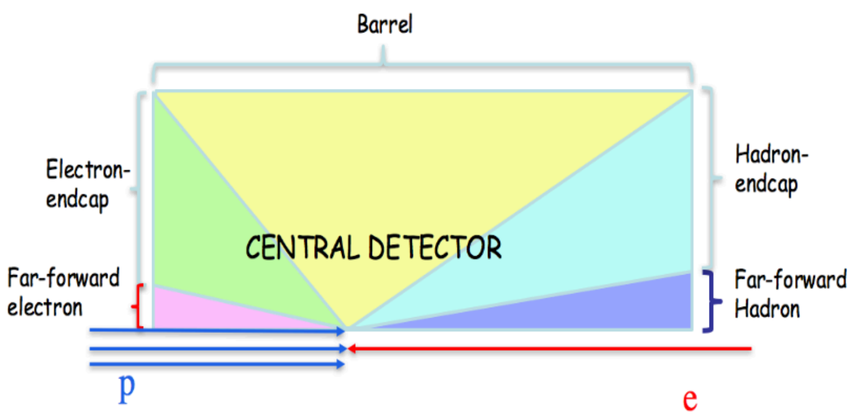
ZEUS: ~2%

JLEIC: ~100%

Rik Yoshida

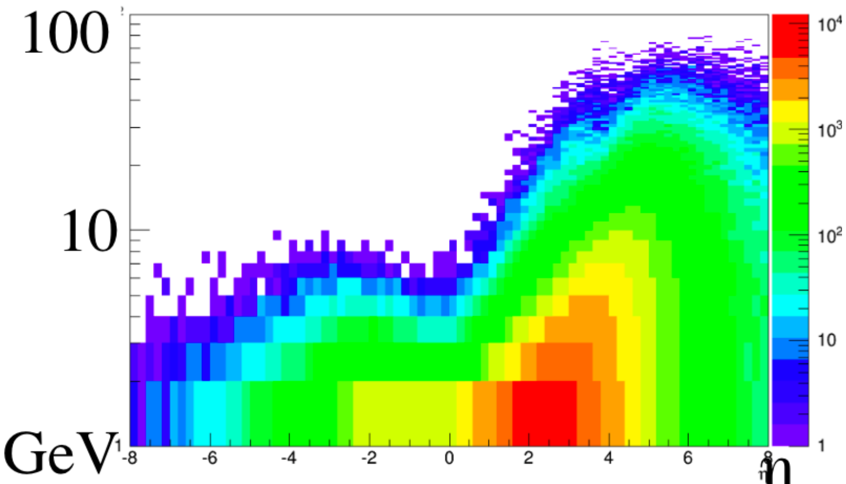
Particle Distribution

	E-endcap	Barrel	H-endcap
E'e	<8 GeV	8-50 GeV	>50 GeV
Ejet	<10 GeV	~10-50 GeV	20-100 GeV
E,hadrons	<10 GeV	<15 GeV	~15-50 GeV
occupancy	low	medium	high



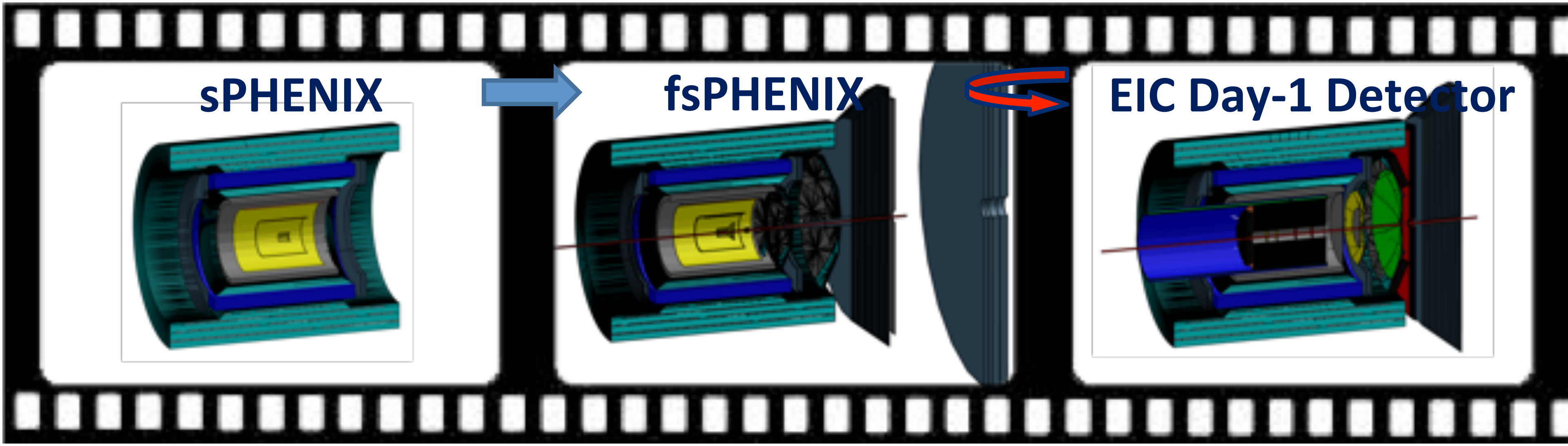
Pythia MC

$\pi^{\pm}$ Energy



Evolution of PHENIX into a Day-1 EIC Detector

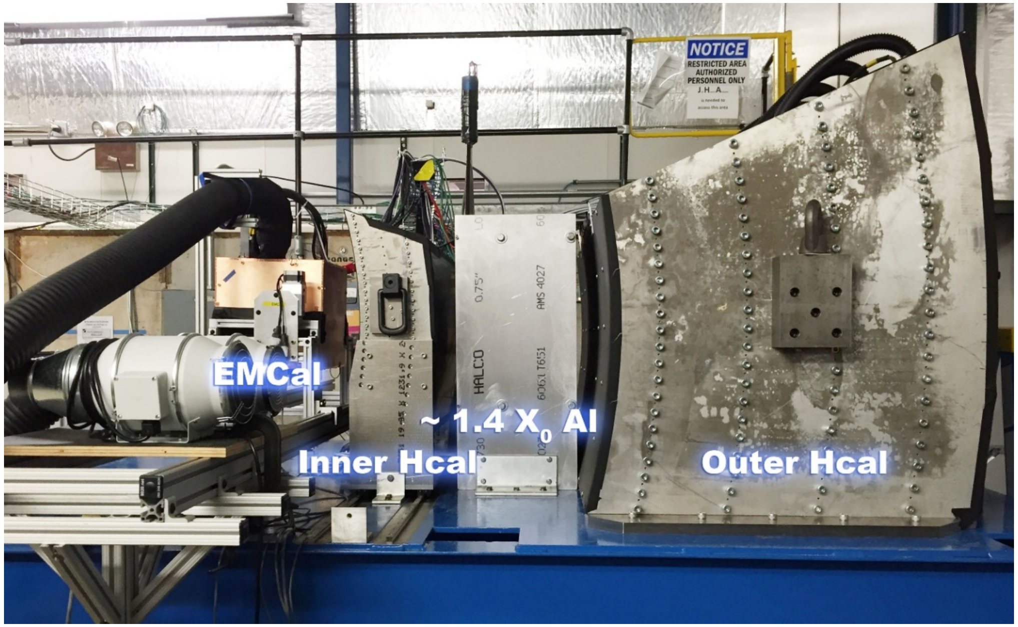
Kenneth N. Barish

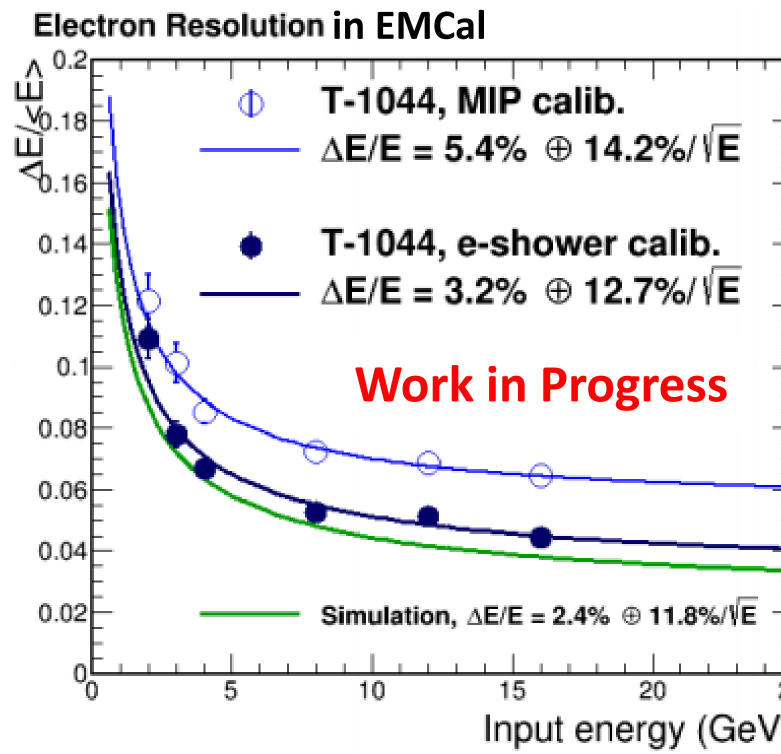


- **sPHENIX**: Centered around BaBar superconducting solenoid (1.5T). **Motivation:** study of Quark Gluon Plasma in heavy-ion collisions via jet structure, heavy-flavor tagged jets, and Upsilon spectroscopy.
- **fsPHENIX**: addition of forward instrumentation (EMCal, Hcal, GEM trackers, Roman Pots?, to realize unique physics potential of polarized p+p, p+A, and A+A collisions.
- **EIC Day-1 Detector**: further evolution into an EIC detector. Add Crystal EMCal, and tracking in electron going, further add PID in barrel and hadron going, and additional tracking in hadron direction
- Takes advantages of significant investment in sPHENIX, and has coverage and resolutions to do essential Day-1 EIC physics.

Kenneth N. Barish

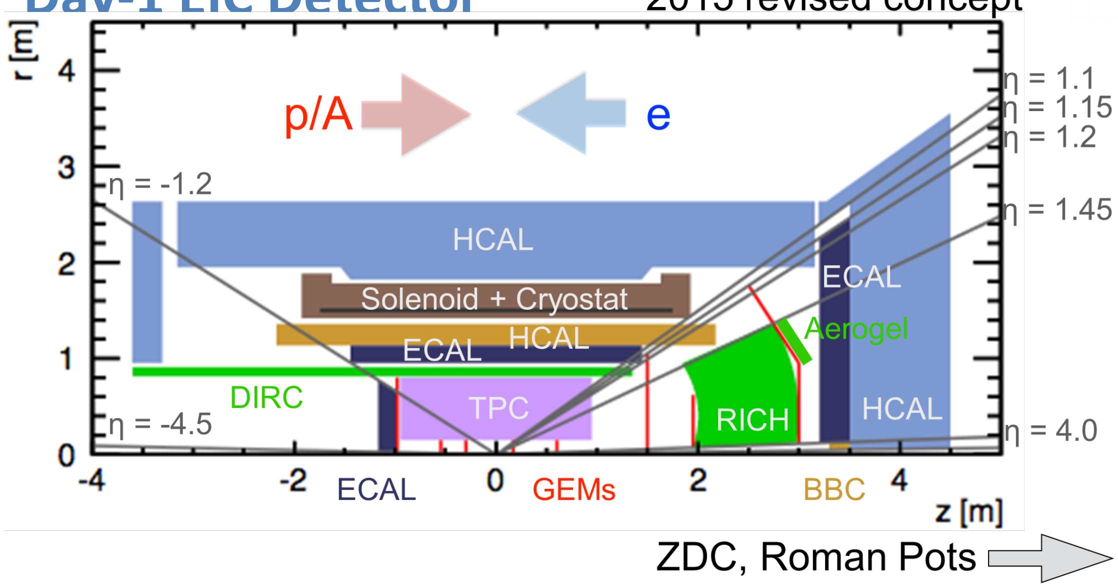
Beam Test Preliminary results





Day-1 EIC Detector

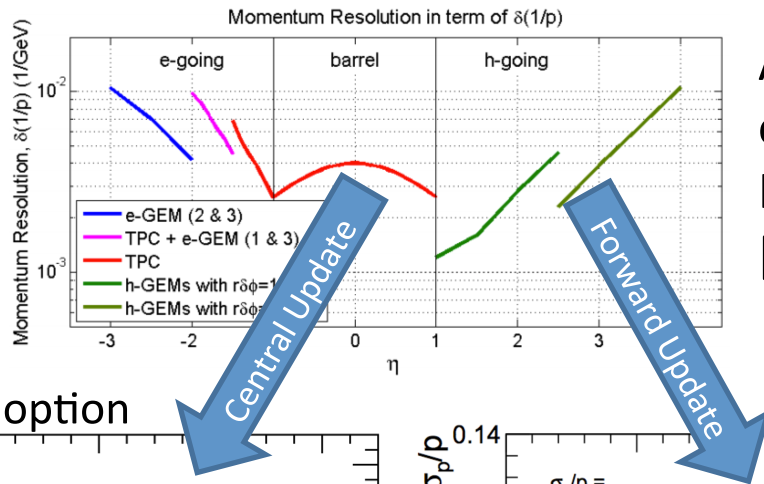
'2015 revised concept'



- Simulation shows good agreement with early **data** results
- Expect to achieve required resolution of 12%/√E

Kenneth N. Barish

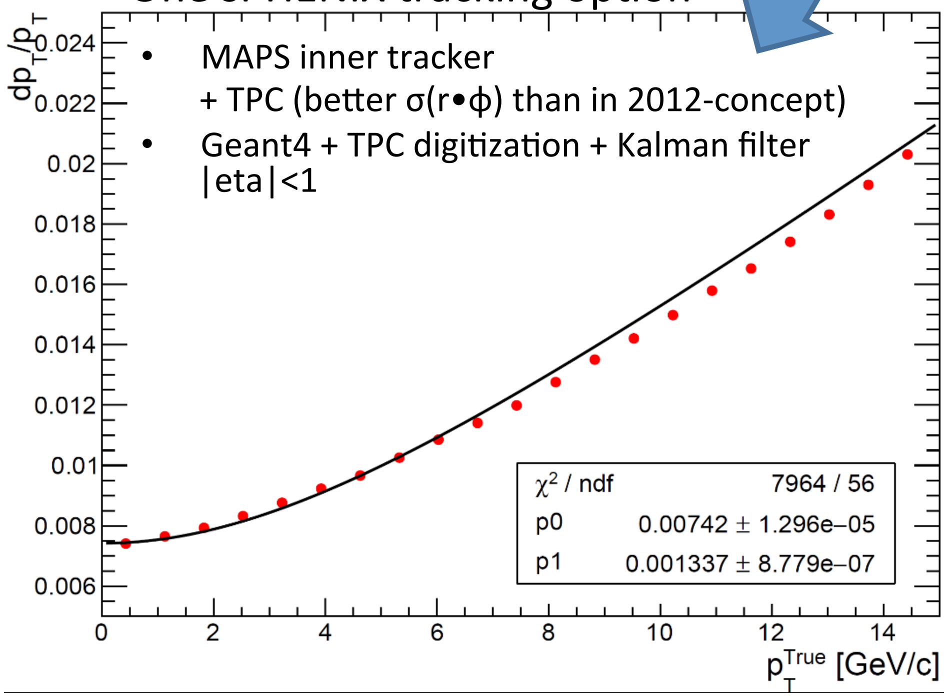
Tracking Updates



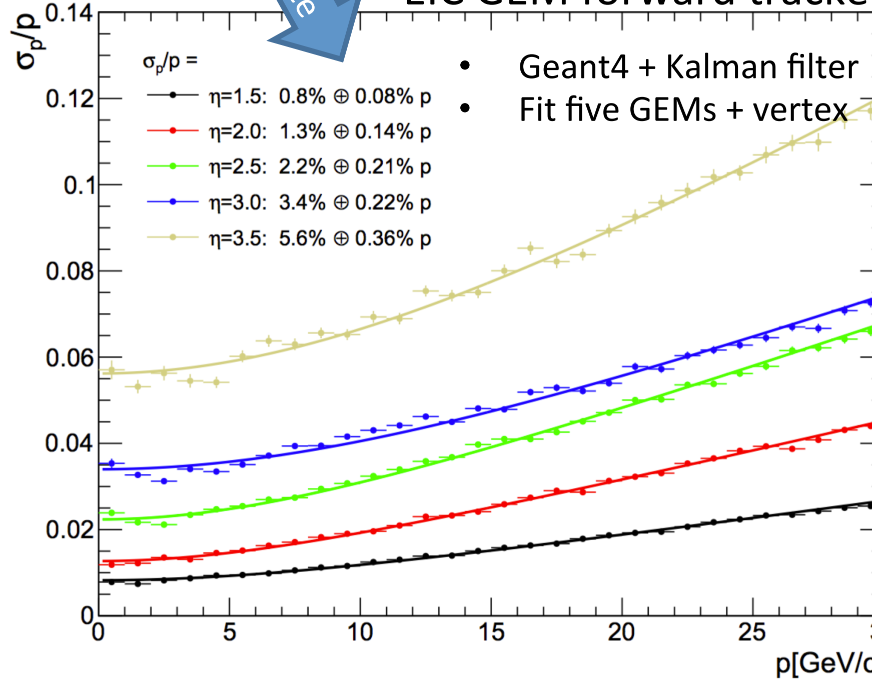
Analytical estimation
of linear resolution term
In 2012-concept
[arXiv:1402.1209v1]

MS: < 1% (low η) to 3% (η = 3)

One sPHENIX tracking option

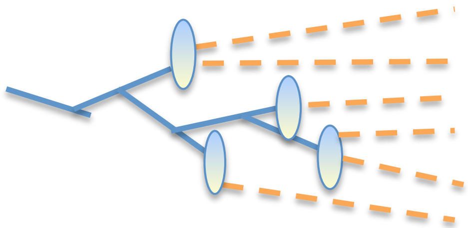


EIC GEM forward tracker

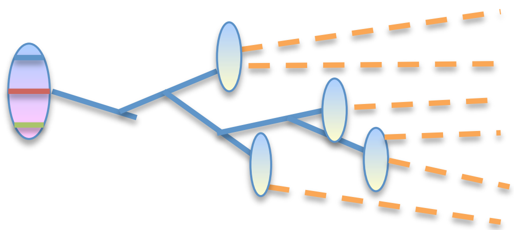


Yulia Furletova

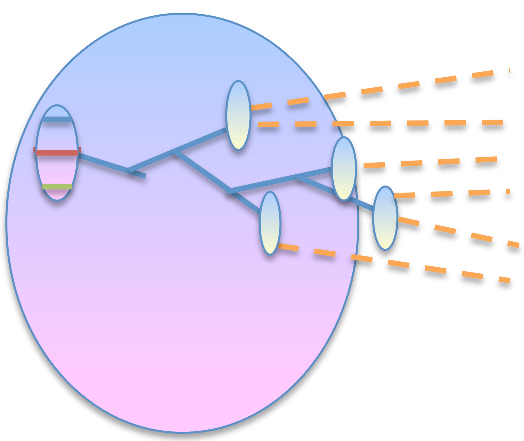
PHYSICS WITH JETS AT EIC



1) **Jets evolution and dynamics**
   - ✓ radiation/hadronization mechanism.
   - ✓ formation of a jet
   - ✓ reconstruction algorithms



2) **Jets as a probe of partonic initial state**
   - ✓ gluons (at high x) , quarks/anti-quarks

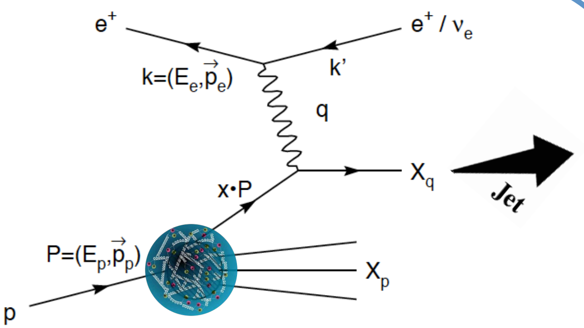


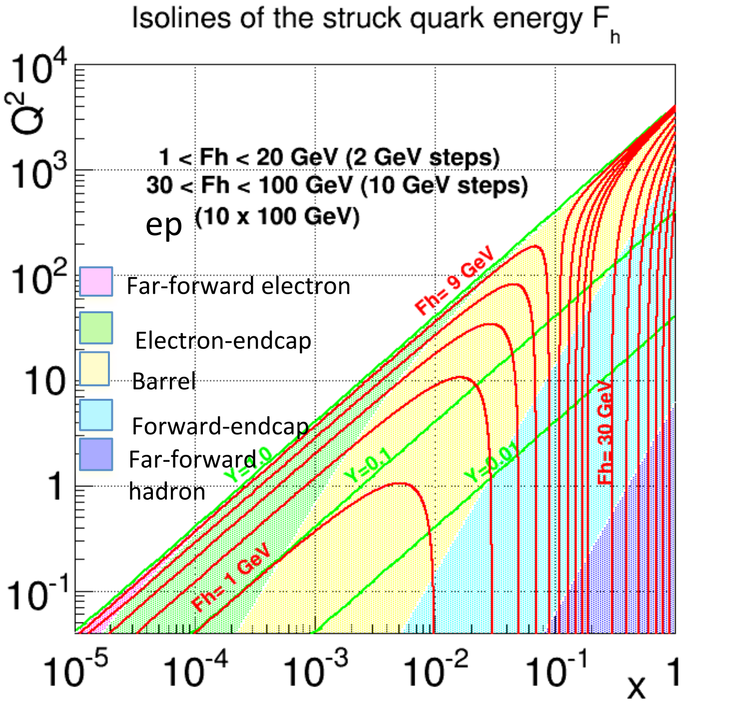
3) **Jets in medium**
   - ✓ energy loss, quenching
   - ✓ broadening
   - ✓ multiple-scattering.

Yulia Furletova

JETS AT EIC

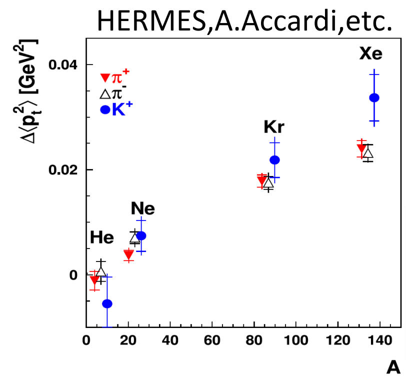
Jet approximates a parton

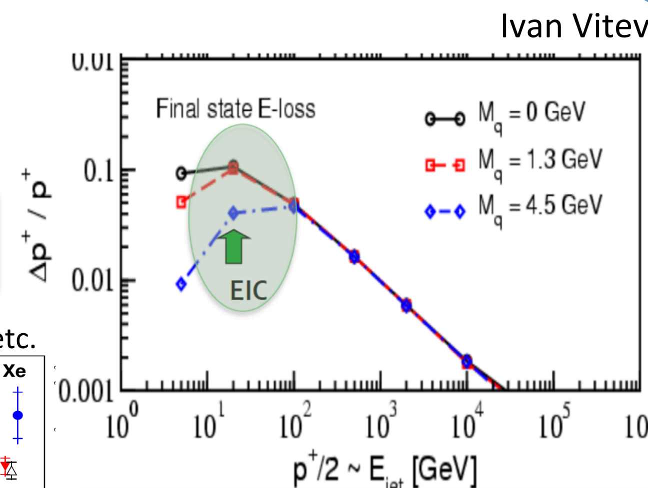




Struck quark energy Fh ~1-100 GeV

Jets Pt-broadening





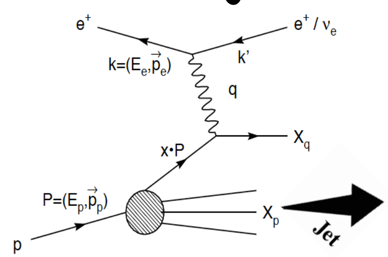
E-loss mass dependence. Heavy-quark in-medium propagation.

At EIC for the first time - will be able to study in-medium propagation and hadronization of heavy quarks (charm and beauty)

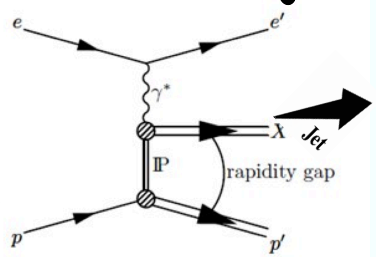
Yulia Furletova

Other Jets at EIC

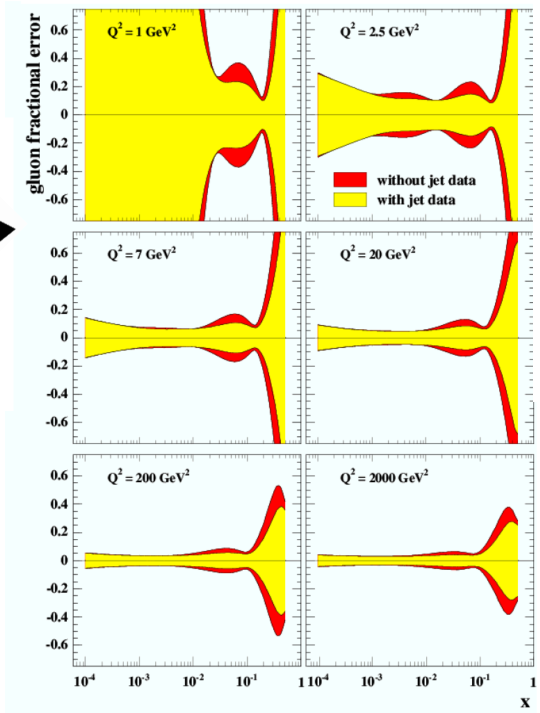
Remnant -jet



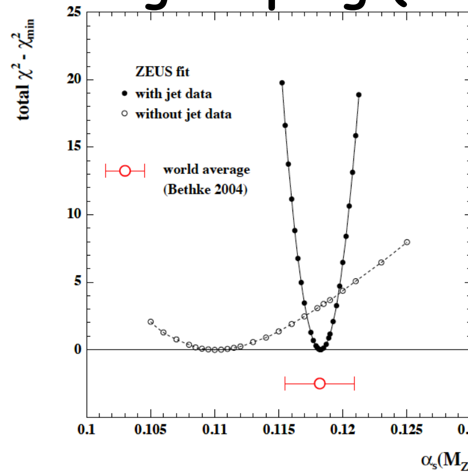
Diffractive -jet



Gluon pdf (HERA)

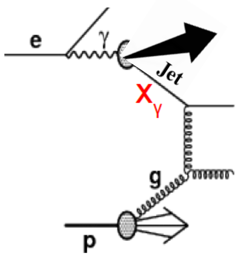


Strong coupling (HERA)

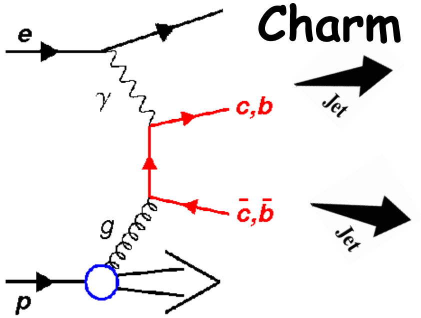


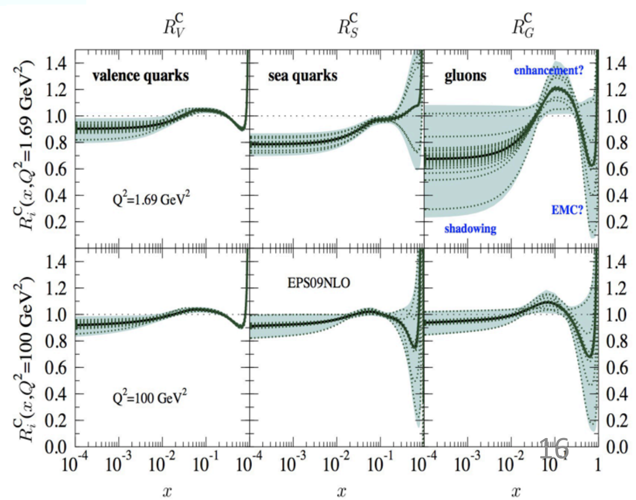
Photon remnant

$x_\gamma<1$

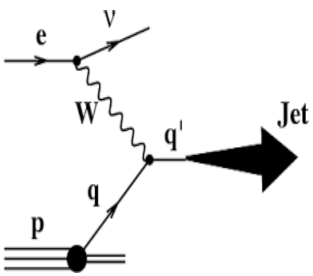


Charm jet

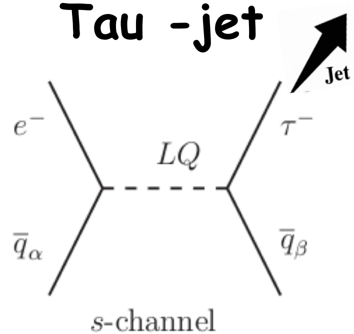




Charged current DIS

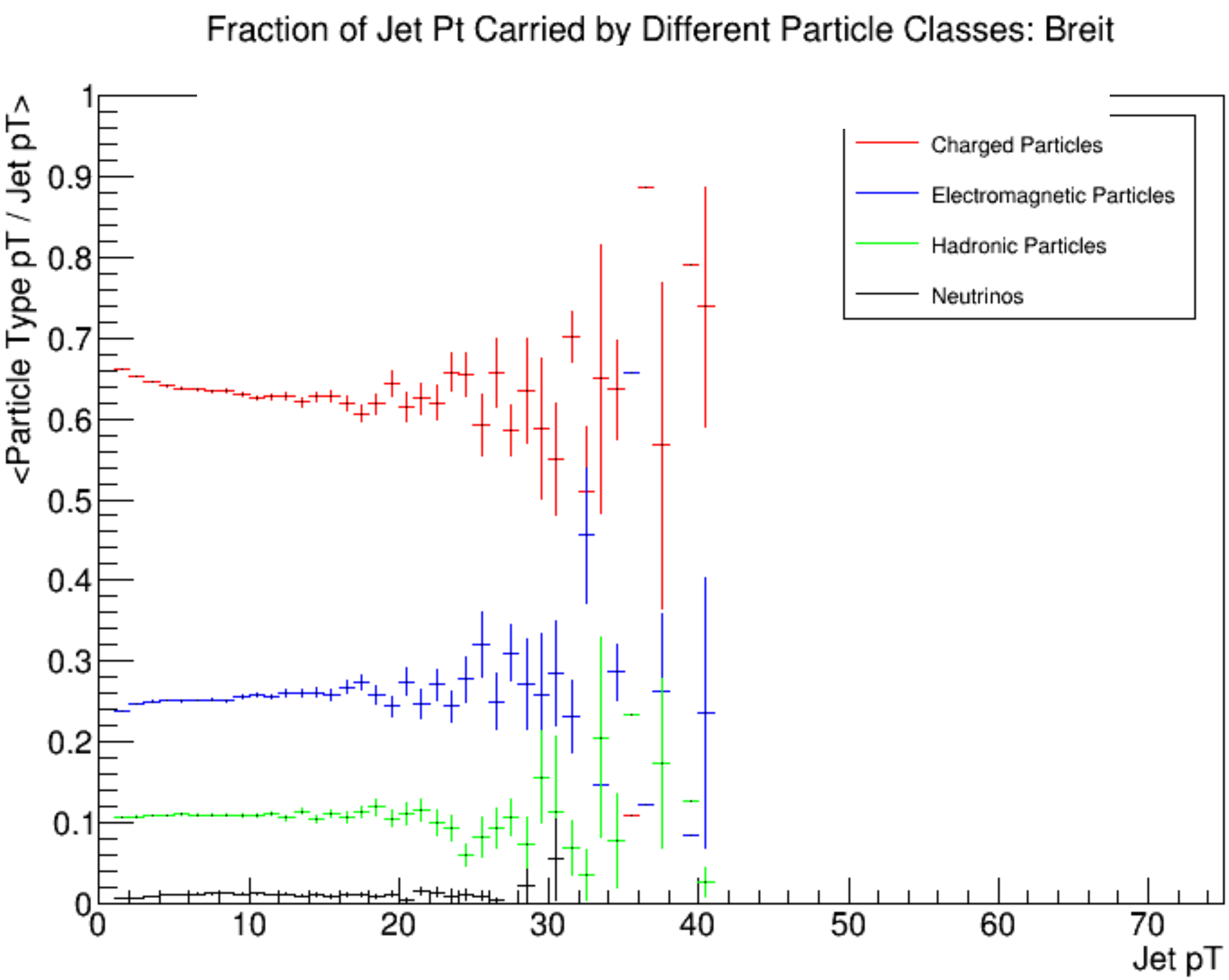


Tau -jet



Particle p_T Fractions Vs Jet p_T

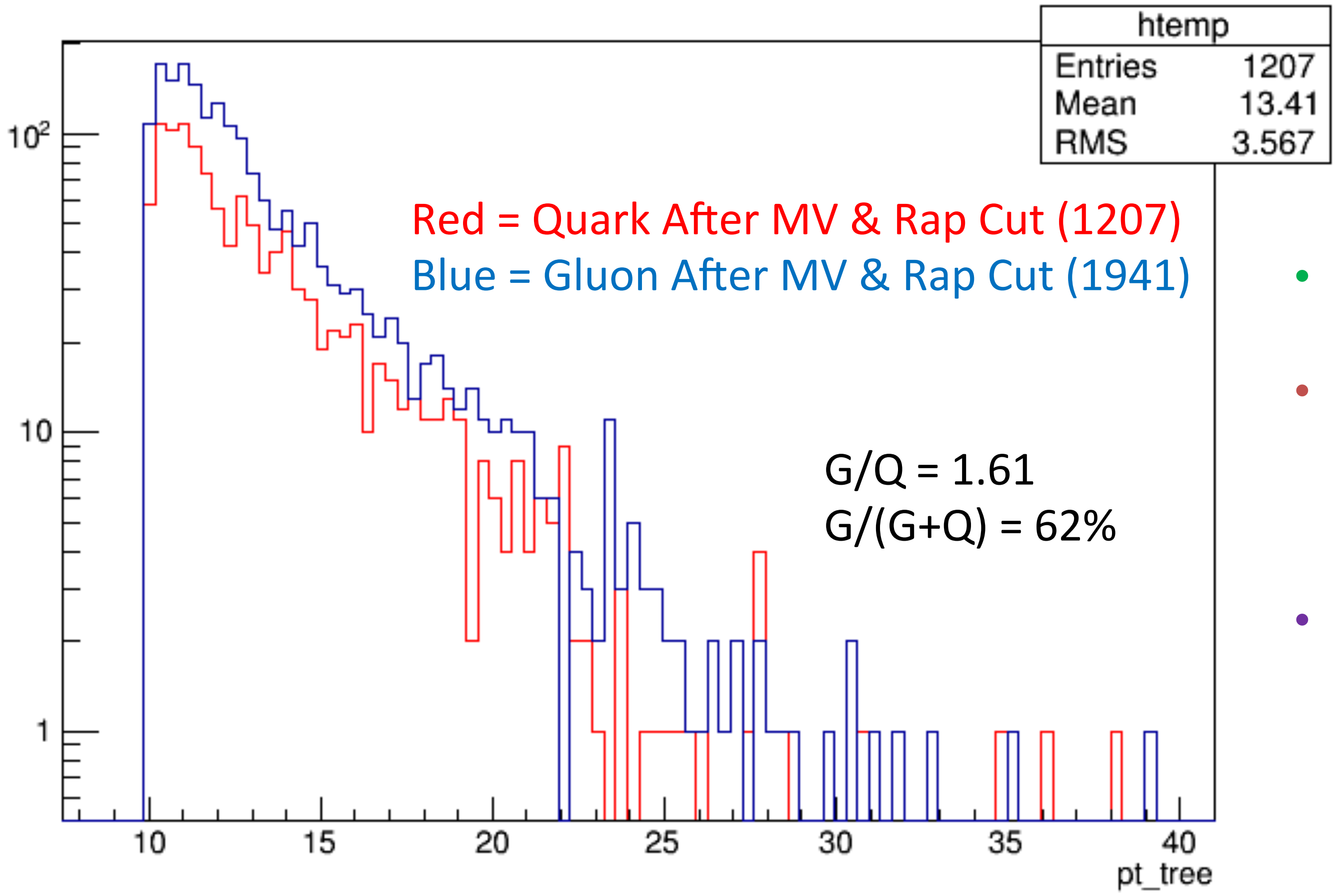
Brian Page



- Take vector sum of particles of given type and find total transverse momentum
- Plot average p_T of each particle class vs total jet p_T
- See that charged particles dominate while neutral hadrons contribute roughly 10%

Jet p_T Spectra With Rapidity Cut

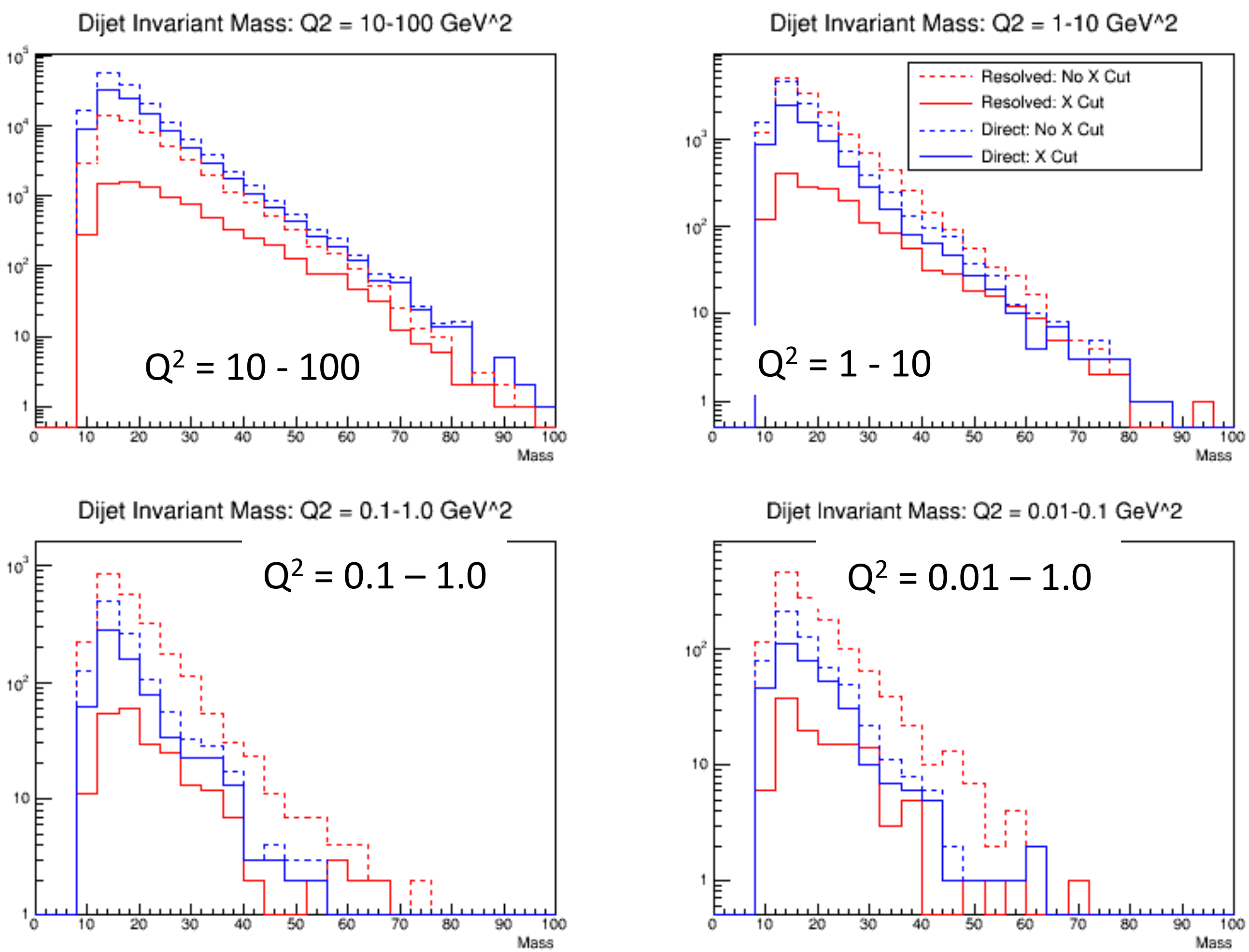
Brian Page



- Plot jet p_T after all cuts
- See reasonable enhancement of gluon jets over p_T range
- Should be able to get relatively pure quark sample and enhanced gluon sample for applications which require identification

Di-jet Invariant Mass

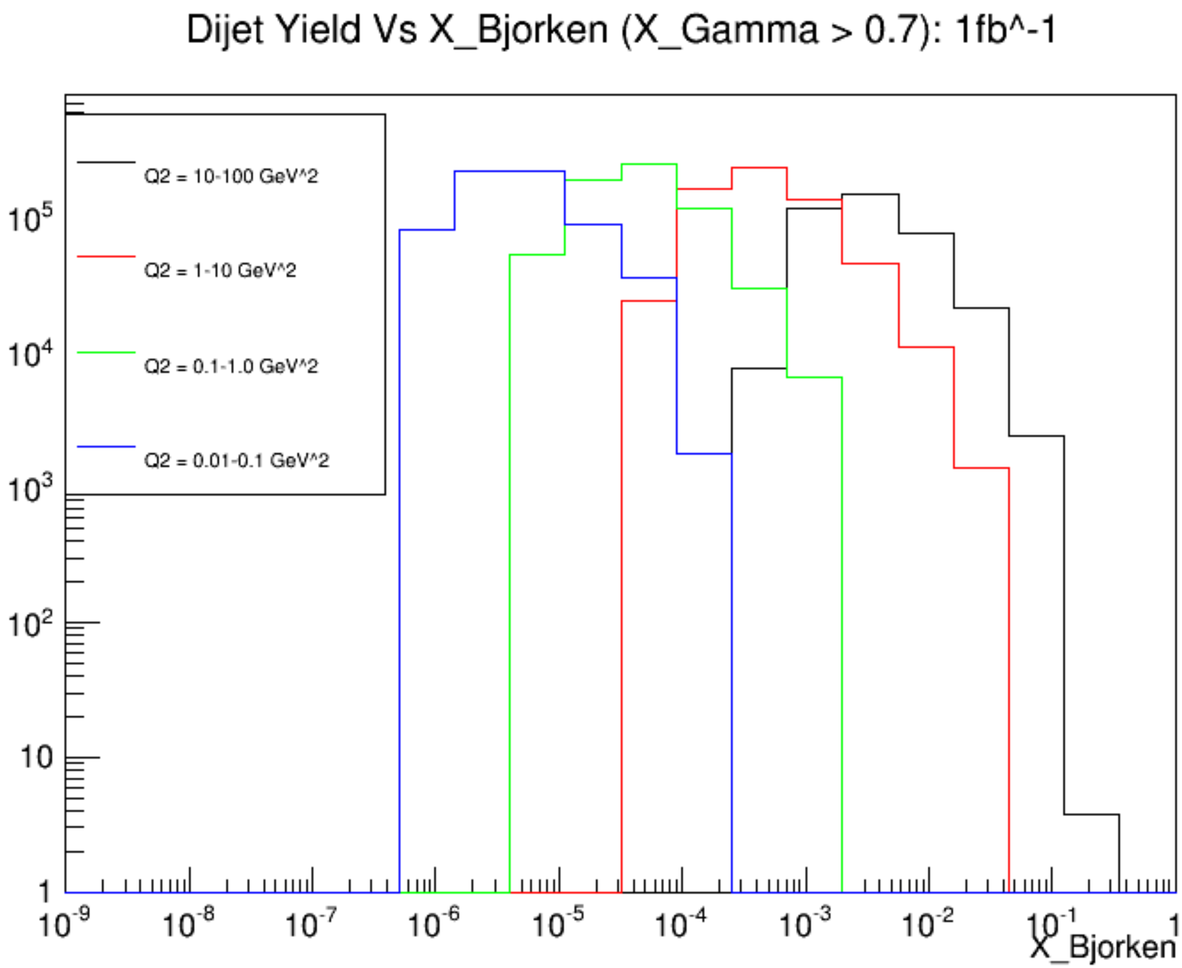
Brian Page



- See that the cut on X_γ significantly reduces the resolved contribution while maintaining the direct events
- Separation between resolved and direct is most prominent at high Q^2 and low di-jet invariant mass
- Further suppression of resolved events may be possible by looking at lab-frame rapidity correlations

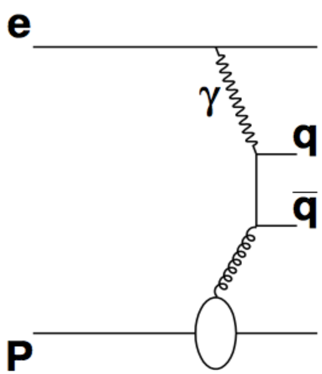
Di-jet Yield in X and Q^2: $1fb^{-1}$

Brian Page

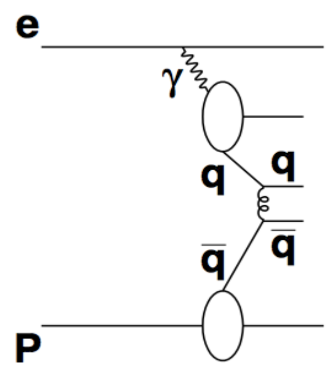


- Yield of di-jet events which pass X_γ cuts vs x_B for the four Q^2 bins simulated
- Yield has been scaled to an integrated luminosity of $1fb^{-1}$
- See multiple decades of Q^2 coverage for several x_B bins
- Different x_B ranges can be accessed at a given Q^2 by varying the collision energy
- Study is in early stage but outlook is positive – can isolate direct contribution even at low Q^2

- There are two types of processes which can produce di-jet through hard scattering: direct and resolved process.

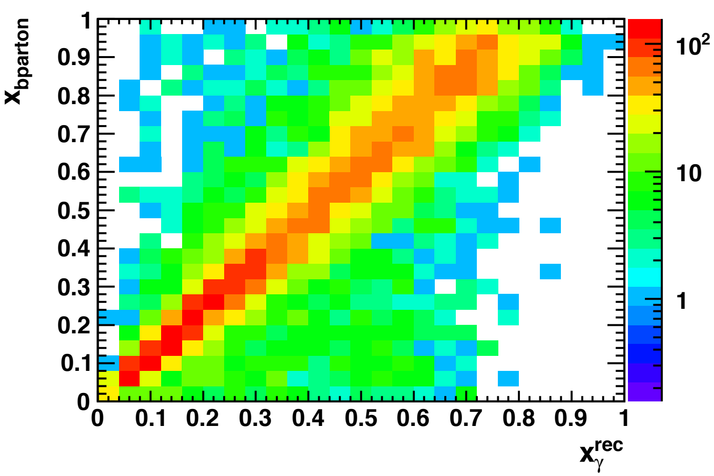


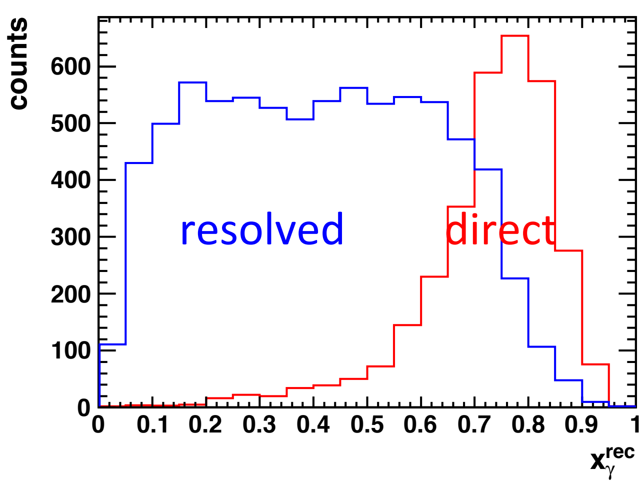
direct



resolved

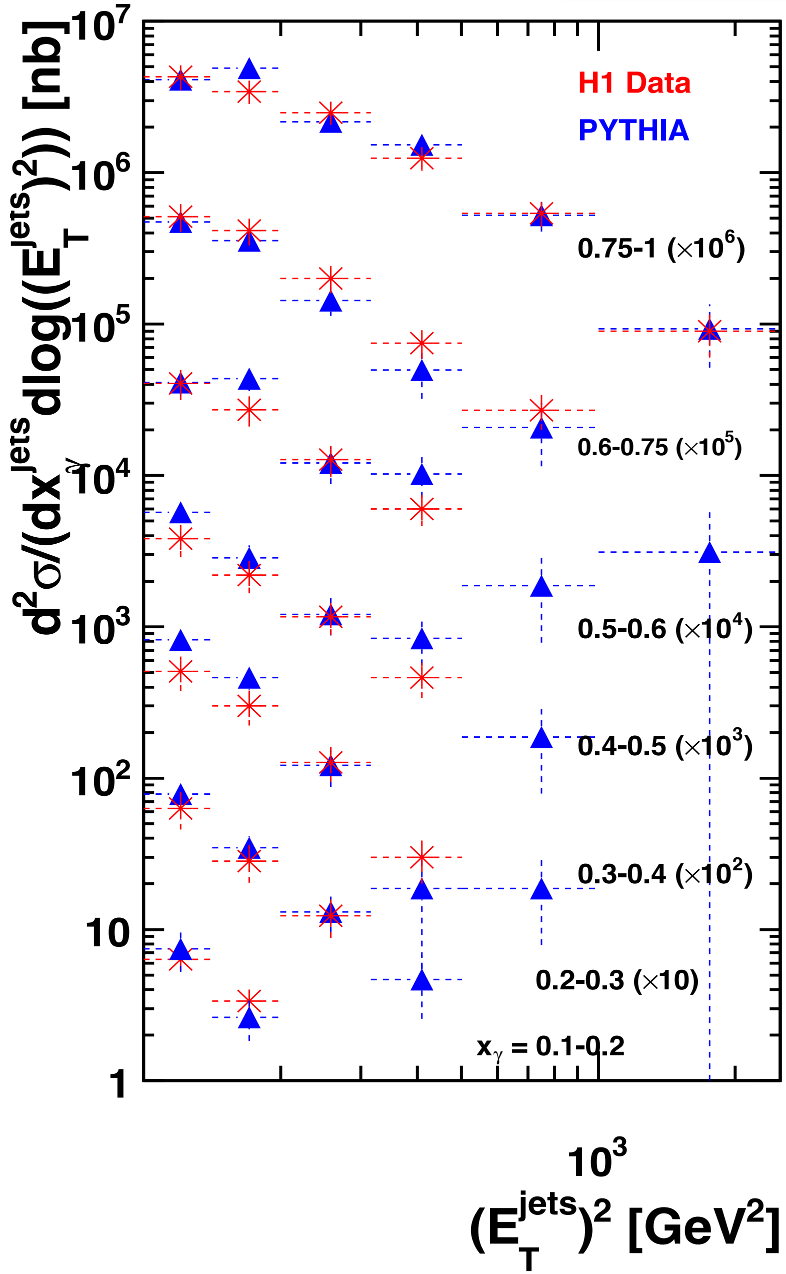
- Only in resolved process, the photon has a structure. Then we can separate theses two types of processes at EIC by reconstructing x_γ

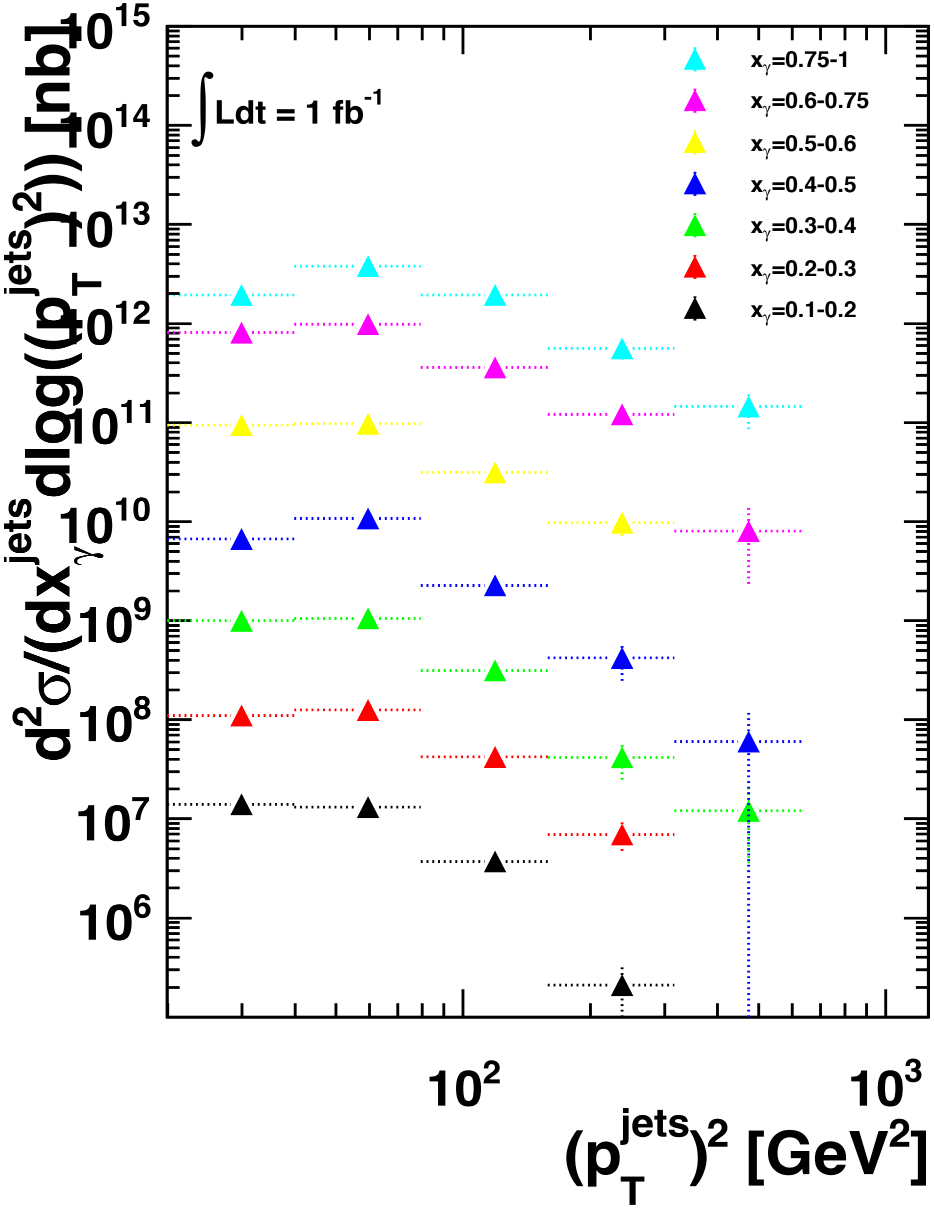




- Photon PDFs can be extracted by measuring di-jet cross section in photoproduction events.

- **We can reproduce the HERA data by using EIC simulation** to measure di-jet cross section in photoproduction events (seen the figure on right), which indicates our EIC simulation is reliable.

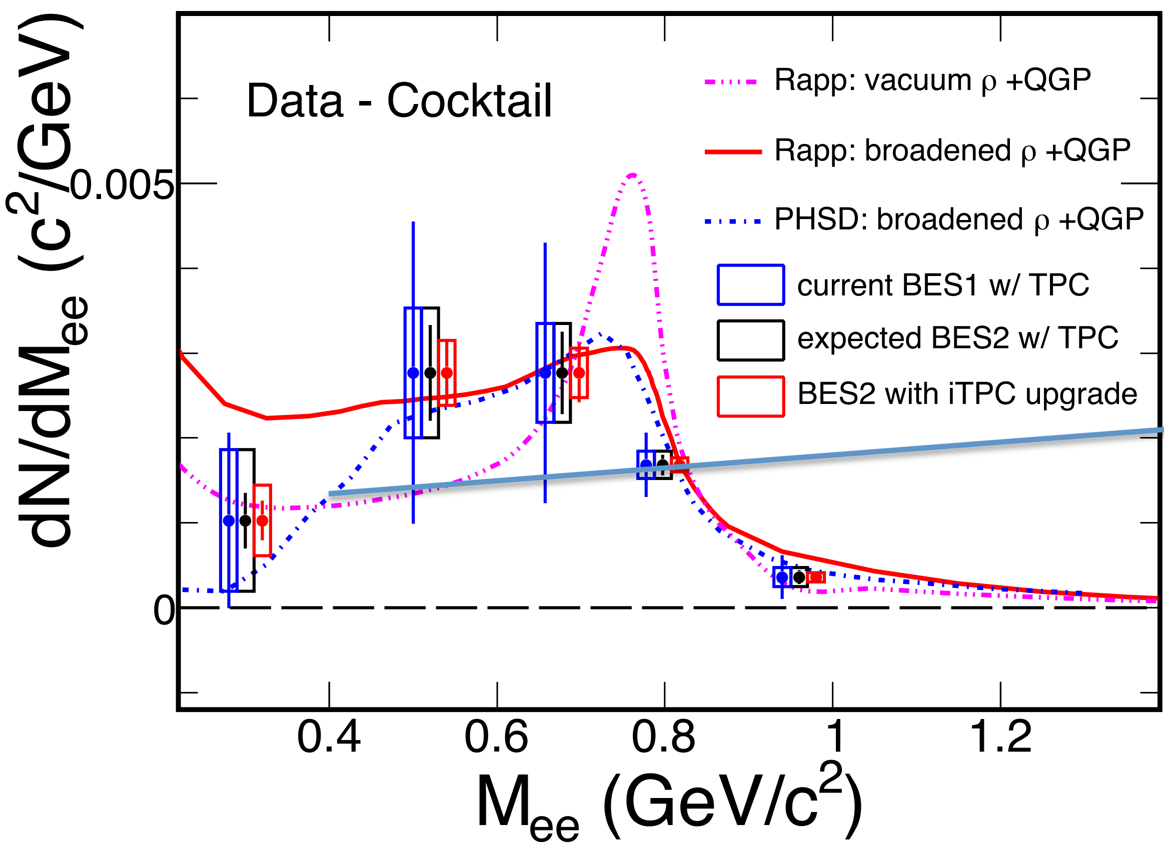




Di-jet cross section measured at EIC

- The simulation shows the capability to measure the cross section for di-jet production, with high accuracy in a wide kinematic range at EIC and extract the photon PDFs from a global fit.

Distinguish the mechanisms of rho broadening

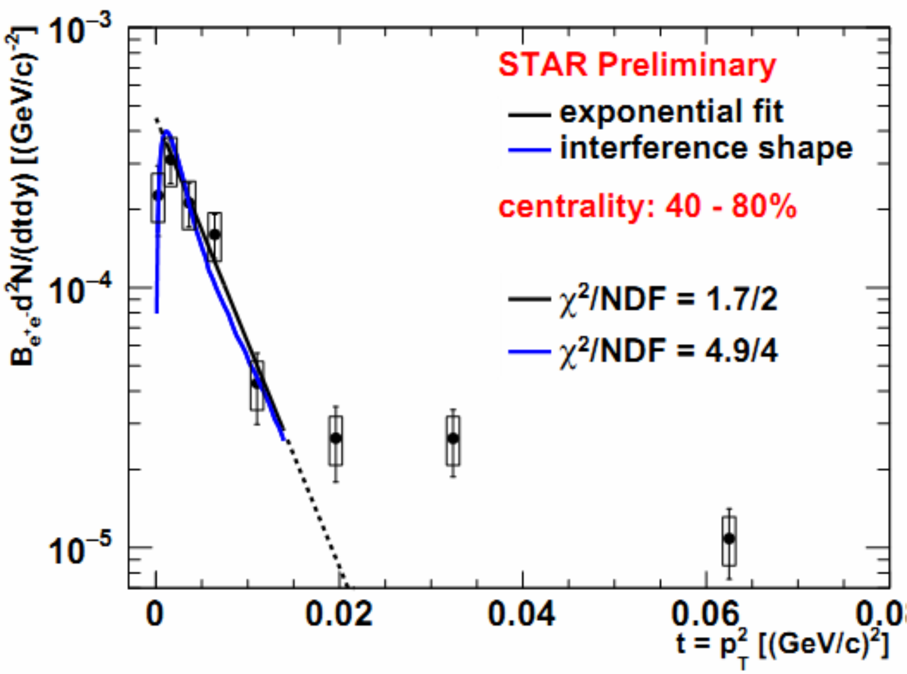


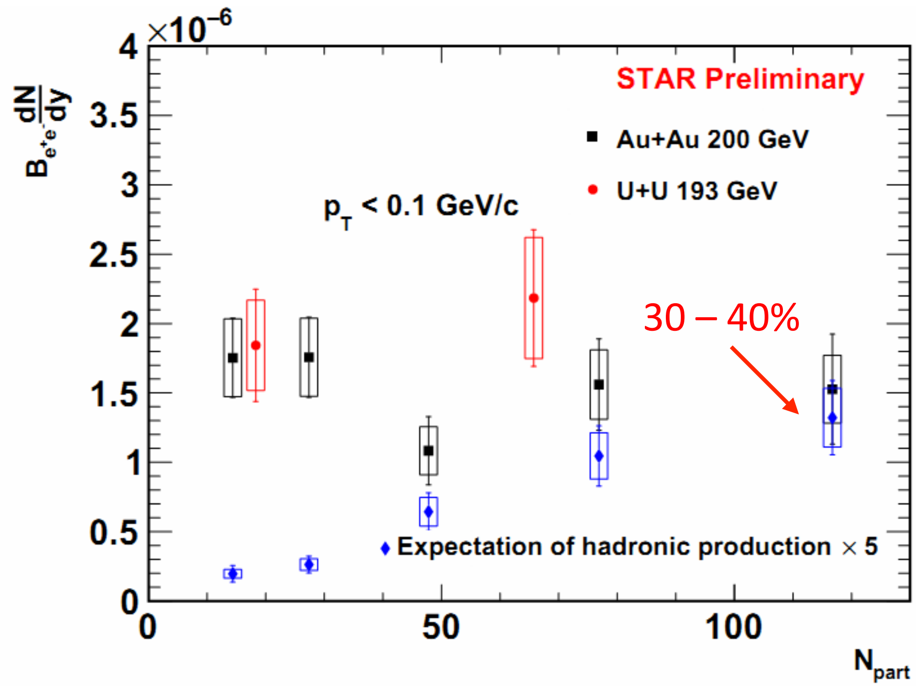
Possible to distinguish between models (blue and red curves) after upgrade (red errors)

Knowing the mechanism that causes in-medium rho broadening and its temperature and baryon-density dependence is fundamental to our understanding and assessment of chiral symmetry restoration in hot QCD matter !

Turn off hot medium effect: electron-positron pair at the EIC? Understanding the rho modifications in cold nuclear matter (e+A versus e+p) is fundamental!

J/ψ yield :$t=p_T^2$ and centrality dependence



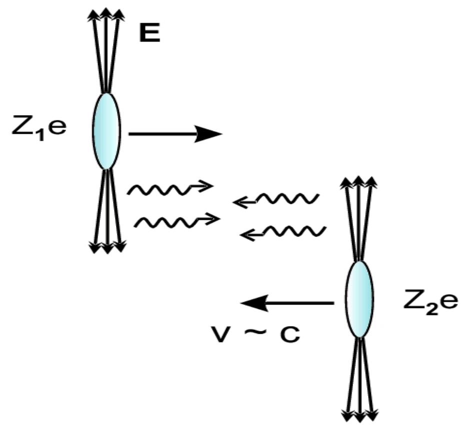


Slope parameter consistent with the size of the Au nucleus. Interference structure observed. Coherent photon-nucleus interactions?

No significant centrality dependence of the excess yield! Interplay between photon flux cancellation in the overlapped area and the distance of the spectators of the two nuclei?

Simulations ongoing and need theoretical inputs!

Coherent photonuclear and two-photon processes



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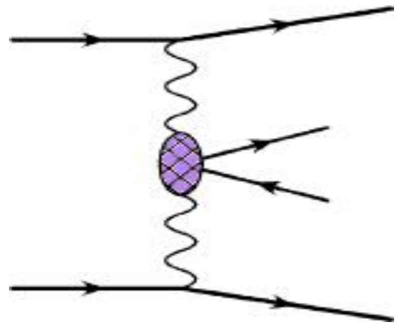
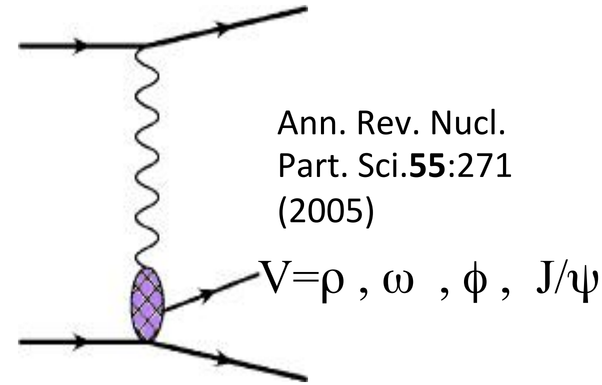


Two-photon

+



photonuclear

Ann. Rev. Nucl. Part. Sci.**55**:271 (2005)

Studied extensively in ultra-peripheral collisions

How is **the J/ψ from coherent photonuclear process affected by hot and cold QCD matter! Why do we still be able to observe** these J/ψs**?**
A new tool to study enriched multi-body dynamics on the strong QCD force!

EIC serves as an ideal factory to study the cold QCD matter effect.

Study the very low p_T J/ψ production as a function of p_T^2, multiplicity, and system size dependences (by varying nucleus type) in e+A collisions and also compare the measurements in e+A to those in e+p one (R_{eA}). Is it feasible?

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Electroweak physics at the EIC

parity violating asymmetries are associated with a new series of structure functions

EIC offers new opportunities to access new structure functions and measure weak mixing angle at high Q^2

With parity violation and $Q^2 << Z^2$

pol. electron & unpol. nucleon:

$$A_{beam} = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}[g_A^e \frac{F_1^{\gamma Z}}{F_1^{\gamma}} + g_V^e \frac{Y_-}{2Y_+}\frac{F_3^{\gamma Z}}{F_1^{\gamma}}]$$

unpol. electron & pol. nucleon:

$$A_L = \frac{G_F Q^2}{2\sqrt{2}\pi\alpha}[g_V^e \frac{g_5^{\gamma Z}}{F_1^{\gamma}} + g_A^e \frac{Y_-}{Y_+}\frac{g_1^{\gamma Z}}{F_1^{\gamma}}]$$

$$F_1^{p,\,\gamma Z} \approx \frac{1}{9}(u+\bar{u}+d+\bar{d}+s+\bar{s}+c+\bar{c})$$

$$F_1^{n,\,\gamma Z} \approx \frac{1}{9}(u+\bar{u}+d+\bar{d}+s+\bar{s}+c+\bar{c})$$

$$F_3^{p,\,\gamma Z} = \frac{2}{3}(u_V+c-\bar{c})+\frac{1}{3}(d_V+s-\bar{s})$$

$$F_3^{n,\,\gamma Z} = \frac{2}{3}(d_V+s-\bar{s})+\frac{1}{3}(u_V+c-\bar{c})$$

$$g_1^{p,\,\gamma Z} \approx \frac{1}{9}(\Delta u+\Delta\bar{u}+\Delta d+\Delta\bar{d}+\Delta s+\Delta\bar{s}+\Delta c+\Delta\bar{c})$$

$$g_1^{n,\,\gamma Z} \approx \frac{1}{9}(\Delta u+\Delta\bar{u}+\Delta d+\Delta\bar{d}+\Delta s+\Delta\bar{s}+\Delta c+\Delta\bar{c})$$

$$g_5^{p,\,\gamma Z} = \frac{1}{3}(\Delta u_V+\Delta c-\Delta\bar{c})+\frac{1}{6}(\Delta d_V+\Delta s-\Delta\bar{s})$$

$$g_5^{n,\,\gamma Z} = \frac{1}{3}(\Delta d_V+\Delta s-\Delta\bar{s})+\frac{1}{6}(\Delta u_V+\Delta c-\Delta\bar{c})$$

Structure functions study with e-p collisions

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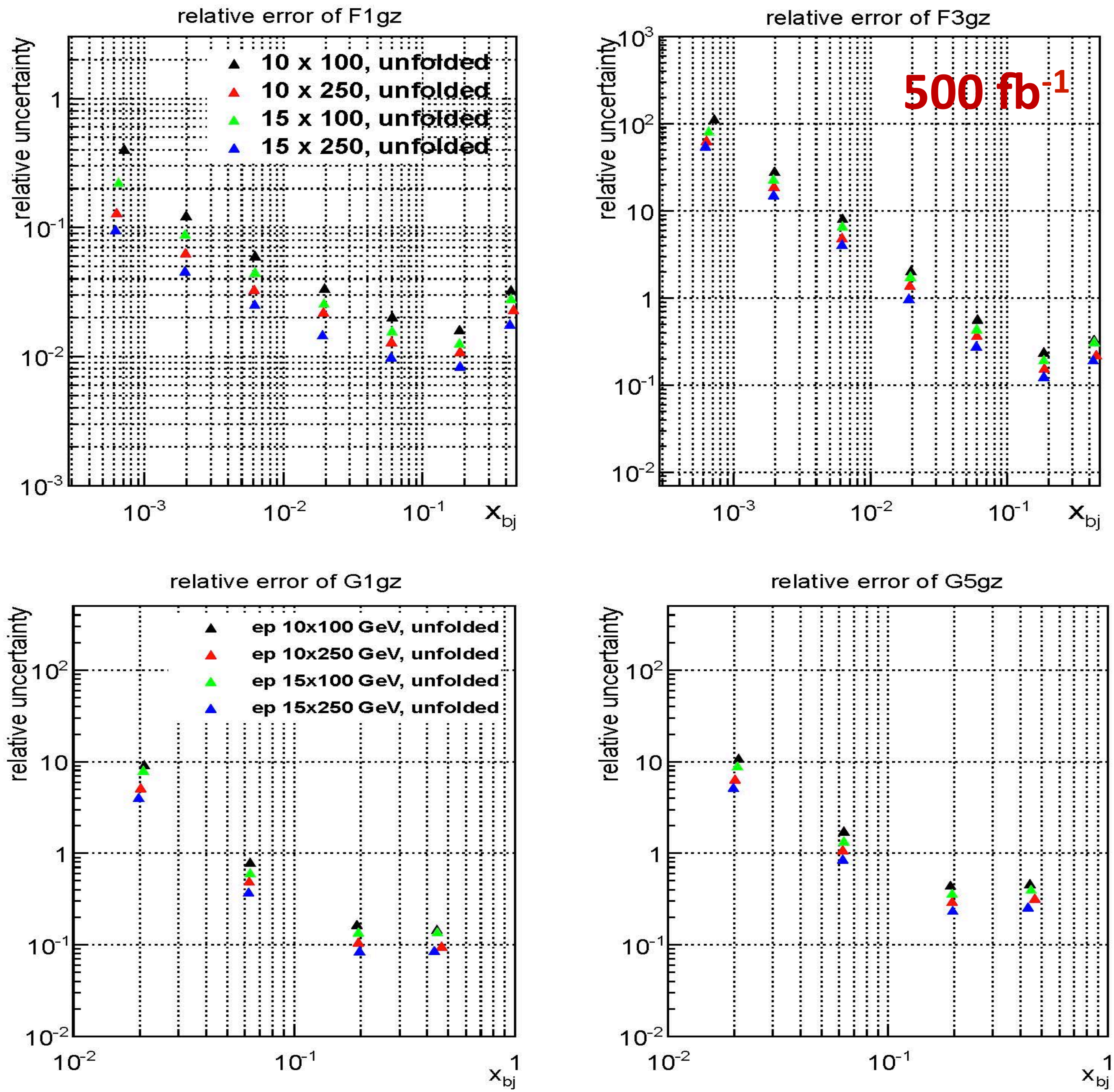

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Weak mixing angle study with e-D collisions